

IN THE MATTER OF  
PATENT APPLICATION

C E R T I F I C A T E

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Dated this 16th day of April, 2008

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(TRANSLATION)

[Name of Document] Application for Patent  
[Reference Number] 2032450071  
[Filing Date] April 4, 2003  
[Destination] Commissioner  
[International Patent Classification] G11B 7/00  
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[Reference Number of Previous Payment] 011305

[Amount of Payment] 21,000

[List of Accompanying Documents]

[Name thereof] Specification 1

[Name thereof] Drawings 1

[Name thereof] Abstract 1

[Number of General Power of Attorney] 9809938

[Name of the Document] SPECIFICATION

[Title of the Invention] Method and apparatus for performing optical recording on optical disk medium

[Claims]

[Claim 1] An optical recording method for writing information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers,

wherein the method is characterized by:

classifying mark lengths (code lengths) in a given write code sequence following a predetermined rule;

modulating the power of the laser beam to produce multiple pulses while making recording marks;

changing the numbers of the modulating pulses with the code length;

classifying the code lengths into at least the four groups of  $n$ ,  $n+1$ ,  $n+2$  and  $n+3$  or more, respectively, where  $n$  is a natural number representing the shortest code length; and

generating only one write pulse  $P_w$  if the code length is  $n$ ,  $n+1$  or  $n+2$ .

[Claim 2] The optical recording method of claim 1, characterized in that the number of write pulses  $P_w$  generated to make a mark with a mark length  $x$  of  $n+3$  or more is the quotient obtained by dividing  $(x-1)$  by two.

[Claim 3] The optical recording method of claim 1, characterized in that in a recording mark making period, an erasure power level Pe is maintained for at least 1 Tw.

[Claim 4] The optical recording method of claim 1, characterized in that in a recording mark making period, a bottom power level Pb is maintained for at least 1 Tw.

[Claim 5] The optical recording method of claim 1, characterized in that in a recording mark making period, a cooling power level Pc is maintained for at least 1 Tw.

[Claim 6] The optical recording method of claim 1, characterized in that the start position of the first pulse and the end position of a cooling pulse are shifted according to write code length.

[Claim 7] The optical recording method of claim 6, characterized in that the shift is done to at least four different degrees that are defined for the code lengths of n, n+1, n+2 and n+3 or more, respectively.

[Claim 8] An optical recorder for writing information on an optical disk medium by irradiating the medium with a laser beam while changing its powers and making marks, of which physical properties are different from those of unrecorded portions, the recorder characterized by comprising:

laser driver means for modulating the power of the laser beam;

coding means for transforming the information into a write code sequence; and

mark length classifying means for changing the numbers of pulses to generate in a mark making period in order to modulate the power of the laser beam according to mark length (or code length) in the write code sequence,

wherein the mark length classifying means classifies the code lengths into at least the four groups of  $n$ ,  $n+1$ ,  $n+2$  and  $n+3$  or more, respectively, where  $n$  is a natural number representing the shortest code length, and

wherein the driver means drives a laser so as to generate only one write pulse  $P_w$  if the code length is  $n$ ,  $n+1$  or  $n+2$ .

[Claim 9] The optical recorder of claim 8, characterized in that the driver means drives the laser such that the number of write pulses generated to make a mark with a code length  $x$  of  $n+3$  or more is the quotient obtained by dividing  $(x-1)$  by two.

[Claim 10] The optical recorder of claim 8, characterized in that the laser driver means is designed such that every interval between trailing and leading edges of two laser pulses in the mark making period becomes at least equal to a detection window width  $T_w$ .

[Claim 11] The optical recorder of claim 8, characterized by further comprising pulse shifting means for shifting the start position of the first pulse and the end position of a cooling pulse according to write code length.

[Claim 12] The optical recorder of claim 8, characterized by further comprising pulse shifting means for

shifting the start position of the first pulse and the end position of the last pulse according to write code length.

[Claim 13] The optical recorder of claim 8, characterized by further comprising write compensation means for shifting the positions to at least four different degrees that are defined for the code lengths of n, n+1, n+2 and n+3 or more, respectively.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to an optical recording method and an optical disk recorder for writing information on an optical disk medium by irradiating the medium with a laser beam and making a mark with a different physical property from a non-recorded portion thereof.

[0002]

[Prior Art]

A DVD-RAM or any other optical disk of a similar type is a phase change disk that makes a mark as an amorphous area on a recording film thereof by irradiating it with a laser beam and controlling the power of the laser beam during heating such that the recording film will cool at variable rates. To increase the information transfer rate while information is being read from, or written on, any of those optical disk media, either the recording linear density or the scanning rate of the beam spot on the storage medium may be increased.

In order to increase the recording linear density, it is effective to reduce the mark length and space length or to narrow the mark edge position detecting interval by reducing the steps of variations in mark and space lengths. However, if the recording linear density were increased, then the SNR of the read signal would pose a problem. In that case, a significant increase in recording linear density should not be expected.

[0003]

To make very small marks on an optical disk with high precision, according to a first conventional technique, a write waveform corresponding to a mark making period is defined as a train of pulses representing the length of a mark (i.e., the length of code) in a write code sequence, and the number and amplitudes of those pulses are controlled according to the length of the write code sequence (see Patent Document No. 1, for example). The write waveform during the mark making period can be divided into a top portion and a succeeding portion. The respective pulses generally have different pulse heights. Also, in non-mark making periods of the write waveform, a write auxiliary pulse is generated to follow the space. Thus, according to this first conventional technique disclosed in the publication cited above, the diffusion of heat from a preceding mark toward the front edge of the very next mark can be compensated for, and the mark width and mark edge position

can be controlled with high precision, irrespective of the space length.

[0004]

According to a second conventional technique, each write code is broken down into a plurality of primitive elements with multiple different lengths such that a single write pulse is assigned to each of those elements. And each write code is defined as a series of independent recording marks associated with multiple write pulses (see Patent Document No. 2, for example).

[0005]

A third conventional technique adopts a multi-pulse writing method that uses the first heating pulse, a number of succeeding heating and cooling pulses that follow the first pulse, and the last cooling pulse. According to the third conventional technique, in recording a mark, of which the length is either an odd number of times or an even number of times as long as one period of a write channel clock, the pulse width of the succeeding heating and cooling pulses is made nearly equal to the length of one period of the write channel clock (see Patent Document No. 3, for example).

[0006]

According to a fourth conventional technique, the energy and the number of pulses that are applied while a mark of an arbitrary length is being made are changed according to the length of the mark in a write code sequence such that the gap

between two arbitrary variation points of the energy applied per unit time during the mark making period becomes longer than a half of the detection window width (see Patent Document No. 4).

[0007]

[Patent Document No. 1]

Japanese Patent Application Laid-Open Publication No. 5-298737

[Patent Document No. 2]

Japanese Patent Application Laid-Open Publication No. 8-7277

[Patent Document No. 3]

Japanese Patent Application Laid-Open Publication No. 9-134525

[Patent Document No. 4]

Japanese Patent Application Laid-Open Publication No. 11-175976

[0008]

[Problems to Be Solved by the Invention]

According to the first conventional technique, the length of a mark, corresponding with the detection window width, is associated with one shot of write pulse. Thus, if the detection window width is shortened, then the semiconductor laser diode, functioning as a source of generating write energy, needs to be driven faster than usual. For example, if one tries to realize a burst transfer rate of

10 megabytes per second, which is almost as high as that of a magnetic disk drive, by a normal (1, 7) modulation technique, then the detection window width of the read signal will be about 8.3 ns and therefore the shortest write current pulse width will be about 4.2 ns, which is approximately a half as long as the detection window width. However, it usually takes several nanoseconds to activate a semiconductor laser, and it is difficult to generate a write beam pulse accurately. Also, even if a write beam pulse could be generated accurately, normal marks could not be made in a situation where multi-pulse writing is carried out on a medium such as a phase change disk in which the mark making is controlled by the cooling rate of its heated portion. This is because the next beam pulse is radiated before the heated portion is cooled sufficiently. Also, if one tries to realize a burst transfer rate of 10 megabytes per second by the (1, 7) modulation technique, for example, then the amount of time it takes to cool the storage medium will also be about 4.2 ns, which is equal to the shortest write current pulse width. Consequently, marks could not be made properly depending on the property of the storage medium.

[0009]

According to the second conventional technique mentioned above, each write code is broken down into a plurality of primitive elements with multiple different lengths such that a single write pulse is assigned to each of those elements

and that each write code is defined as a series of respectively independent recording marks associated with write pulses. However, this conventional technique does not consider thermal balance between write pulses for respective elements at all. That is why as the recording linear density is increased, it becomes more and more difficult to control the mark edge position. That is to say, in making marks that will form a single write code, the recording marks will have variable widths from one position to another because the quantity of heat accumulated in the recording layer for the top portion of the write code is different from that of heat accumulated there for the terminal portion of the write code. As a result, the edge recording cannot be carried out as intended.

[0010]

In the third conventional technique, a pulse, which is much shorter than the detection window width, may be inserted into the write waveform approximately in the middle of the mark making period, and the mark width changes significantly around there compared to the other portions. According to the document disclosing this conventional technique, when a mark edge recording operation is carried out, the variation in signal amplitude around the center portion of a mark should pose no serious problem as long as the mark edge position is accurate. In a read/write drive that determines read/write conditions by detecting the average level of a read signal,

however, such distortion of the read signal should affect the operation of the drive. As to a phase change storage medium, for example, a signal can be detected as a variation in reflectance just like a phase pit type storage medium. That is why the phase change storage medium and phase pit type storage medium can easily share the same read drive in common. However, since the read signal of the phase pit type storage medium has no such distortion, it is actually difficult to read the phase change storage medium and phase pit type storage medium using the same drive.

[0011]

Also, according to the fourth conventional technique, the write power level of the write pulse train changes stepwise, thus requiring complicated power control. Also, in writing a signal with a code length of 4 Tw, the laser beam needs to be emitted so as to achieve a higher power level than the average one at least for a period of time corresponding to 3 Tw. When a very small mark needs to be made on a high-density storage medium in the near future, such an emission time will be too long to make desired recording marks.

[0012]

As can be seen, none of the conventional techniques mentioned above can contribute to making marks sufficiently accurately when the transfer rate is high or achieving sufficiently high density on the storage layer with good

reliability.

[0013]

[Means for Solving the Problems]

To perform read/write operations with high reliability by making marks with good stability, a write waveform that will not cause any of those problems needs to be selected. Besides contributing to making marks with high accuracy, the write waveform should satisfy the following two requirements. Firstly, the write waveform should make it easy to drive a semiconductor laser as a light source. Secondly, the write waveform should allow the given storage medium ample time for cooling.

[0014]

Thus, to overcome the problems described above, the present invention provides an optical recording method as a method for writing information as edge position information, including marks and spaces of multiple different lengths, on an optical disk medium by irradiating the medium with a laser beam while changing its powers. The method is characterized by: classifying mark lengths (code lengths) in a given write code sequence following a predetermined rule; modulating the power of the laser beam to produce multiple pulses while making recording marks; changing the numbers of the modulating pulses with the code length; classifying the code lengths into at least the four groups of  $n$ ,  $n+1$ ,  $n+2$  and  $n+3$  or more, respectively, where  $n$  is a natural number

representing the shortest code length; and generating only one write pulse  $P_w$  if the code length is  $n$ ,  $n+1$  or  $n+2$ .

[0015]

The optical recording method of the present invention is also characterized in that the number of write pulses  $P_w$  generated to make a mark with a mark length  $x$  of  $n+3$  or more is the quotient obtained by dividing  $(x-1)$  by two.

[0016]

The optical recording method of the present invention is further characterized in that in a recording mark making period, an erasure power level  $P_e$  is maintained for at least 1 Tw.

[0017]

The optical recording method of the present invention is further characterized in that in a recording mark making period, a bottom power level  $P_b$  is maintained for at least 1 Tw.

[0018]

The optical recording method of the present invention is further characterized in that in a recording mark making period, a cooling power level  $P_c$  is maintained for at least 1 Tw.

[0019]

The optical recording method of the present invention is further characterized in that the start position of the first pulse and the end position of a cooling pulse are shifted

according to write code length.

[0020]

The optical recording method of the present invention is further characterized in that the shift is done to at least four different degrees that are defined for the code lengths of n, n+1, n+2 and n+3 or more, respectively.

[0021]

An optical recorder/player according to the present invention is designed to write information on an optical disk medium by irradiating the medium with a laser beam while changing its powers and making marks, of which physical properties are different from those of unrecorded portions. The recorder/player is characterized by including: laser driver means for modulating the power of the laser beam; coding means for transforming the information into a write code sequence; and mark length classifying means for changing the numbers of pulses to generate in a mark making period in order to modulate the power of the laser beam according to mark length (or code length) in the write code sequence. The mark length classifying means classifies the code lengths into at least the four groups of n, n+1, n+2 and n+3 or more, respectively, where n is a natural number representing the shortest code length. The driver means drives a laser so as to generate only one write pulse  $P_w$  if the code length is n, n+1 or n+2.

[0022]

The optical recorder/player of the present invention is also characterized in that the driver means drives the laser such that the number of write pulses generated to make a mark with a code length  $x$  of  $n+3$  or more is the quotient obtained by dividing  $(x-1)$  by two.

[0023]

The optical recorder/player of the present invention is further characterized in that the laser driver means is designed such that every interval between trailing and leading edges of two laser pulses in the mark making period becomes at least equal to a detection window width  $T_w$ .

[0024]

The optical recorder/player of the present invention is further characterized by further including pulse shifting means for shifting the start position of the first pulse and the end position of a cooling pulse according to write code length.

[0025]

The optical recorder/player of the present invention is further characterized by further including pulse shifting means for shifting the start position of the first pulse and the end position of the last pulse according to write code length.

[0026]

The optical recorder/player of the present invention is further characterized by further including write compensation

means for shifting the positions to at least four different degrees that are defined for the code lengths of  $n$ ,  $n+1$ ,  $n+2$  and  $n+3$  or more, respectively.

[0027]

According to the preferred embodiments of the present invention described above, the optical disk medium is given an ample time for cooling and the frequency components of a laser drive current can be reduced. As a result, even when the transfer rate is high, marks can be made with enough accuracy and sufficiently high density can be achieved on the storage layer with good reliability.

[0028]

[Embodiments of the Invention]

Hereinafter, preferred embodiments of the present invention will be described. In the following description of preferred embodiments, a phase change optical disk is used as a storage medium. However, the storage media that may be used in the present invention are not necessarily limited to that type. Rather the technique of the present invention is commonly applicable to any other type of storage medium on which information is written by making a "mark" with a different physical property from the non-recorded portions with some energy applied to the storage medium.

[0029]

In the following description of preferred embodiments, the "write energy level" means the average energy level of a

laser beam in a period of time that is approximately a half as long as the detection window width (which is a unit of variation in the edge position of marks and spaces). If a frequency component that is much higher than the frequency of a period corresponding to the detection window width is superposed on a write waveform for some reason (e.g., to minimize laser noise), then the "write energy level" means an average energy level of a period of time that is long enough to neglect the influence of that frequency component.

[0030]

FIG. 1 illustrates an overall configuration for an optical recorder according to the present invention. The coder 113 receives write data 127 to be written and converts it into a write code sequence (NRZI) 126 representing the marks and spaces to be made on an optical disk 117. The write code sequence 126 is sent to a write waveform generator 112, where the sequence 126 is converted into a level producing signal 125 corresponding to the write pulse waveform. The coder 113 and write waveform generator 112 operate in response to a reference clock signal 128 generated by a reference clock generator 119. The level producing signal 125 is passed to a pulse shifter, which compensates for the pulsed waveform of the level generating signal 125 on the time axis in accordance with a write compensation table value of a write compensator 118, thereby generating a pulse generation signal 130 and forwarding it to a laser driver 111.

[0031]

The laser driver **111** generates a laser drive current **124** responsive to the pulse generation signal **130**, thereby causing a laser **110** to emit a laser beam in accordance with a predetermined write pulse waveform. The laser beam **123** emitted from the laser **110** passes a collimator lens **109**, a half mirror **108** and an objective lens **116** and then is condensed onto an optical disk **117**. The condensed pulsed laser beam **123** heats a portion the recording film, thereby leaving marks and spaces there. In reading information, the rows of marks on the optical disk **117** are scanned with the laser beam **123** with a power level that is low enough to avoid destroying the marks. The light that has been reflected from the optical disk **117** passes the objective lens **116** and half mirror **108** and then enters a detector lens **106**. Then the laser beam passes the detector lens **106** and then is condensed on a photodetector **100**. According to the light intensity distribution on its photosensitive plane, the photodetector **100** converts the incoming light into an electrical signal. This electrical signal is amplified by a pre-amplifier **101** provided for the photodetector **100**, thereby generating a read signal **120** that indicates whether or not there is a mark at the scan point on the optical disk **117**. The read signal **120** is subjected by a waveform equalizer **103** to a waveform equalization process and then converted by a binarizer **104** into a binarized read signal **121**. A decoder **105** converts this binarized read signal **121** in

the opposite way to the coder **113**, thereby generating read data **122**. In this preferred embodiment, the reference clock signal has a frequency of 132 MHz and a Tw of 7.58 ns. Also, in this preferred embodiment, the laser may be a semiconductor laser that oscillates at a wavelength of 405 nm and the objective lens may have an NA of 0.85, for example. The optical disk medium may be either a single-layer disk that has only one information storage layer or a dual-layer disk that has two information storage layers. Also, the optical disk may be either a rewritable optical disk medium that uses a phase change recording material or a write-once optical disk that allows the user to write data there only once. The coding method does not have to be the (1, 7) modulation but may also be a 17 PP modulation or an 8-16 modulation. The 8-16 modulation has the shortest code length of 3 T. In that case, an extra length of one may be added to the code length of this preferred embodiment that uses the (1, 7) modulation.

[0032]

FIG. 2 illustrates an exemplary detailed configuration for the write processing system **129** of the present invention shown in FIG. 1. The write data **127** is converted by the coder **113** into the write code sequence **126** representing mark lengths, space lengths, and information about their top positions. The write code sequence **126** is transmitted to a mark length classifier **201** and a write waveform table **202**. The mark length classifier **201** classifies the mark lengths of

the write code sequence **126** following a predetermined rule and gives the results as a mark length classification signal **204** to the write waveform table **202**. The counter **200** refers to the write code sequence **126** and measures the length of time from a mark top position responsive to the reference clock signal **128**, thereby generating a count signal **205**. In accordance with the write code sequence **126**, mark length classification signal **204** and count signal **205**, the write waveform table **202** outputs the level producing signal **125**, reflecting a predetermined write pulse waveform, to the pulse shifter **115**. The pulsed waveform of the level producing signal **125** is compensated for on the time axis according to the write compensation table value of the write compensator **118** and then sent out as the pulse generation signal **130** to the laser driver **111**. Responsive to the pulse generation signal **130**, the laser driver **111** drives the laser **110**.

[0033]

Portions **(a)** through **(h)** of FIG. 3 show the marks and spaces of write code sequences for a conventional apparatus and the apparatus of the present invention and also show an exemplary operation of generating a write waveform to leave such marks and spaces. In some cases, the length or level of a portion of the write pulse waveform needs to be finely adjusted (i.e., write compensation needs to be carried out) in a certain period for some reason by reference to the preceding and succeeding write patterns and code lengths. In the

following description of the write pulse waveform, when such write compensation is carried out, the write pulse waveform is supposed to be compared to the original one yet to be finely adjusted. For that reason, the write pulse waveform will be described on the supposition that the write pattern remains the same over a rather long distance before and after the mark to be made. As used herein, the "rather long distance" means a distance that is much longer than the distance on a medium to be affected by the application of the write energy for a period of time approximately corresponding to the detection window width. Portion **(a)** of FIG. 3 shows the reference clock signal **128** that is used as a time reference for a write operation.  $T_w$  denotes one clock period. Portion **(b)** of FIG. 3 shows the write code sequence **126** obtained by getting the write data subjected to the NRZI conversion by the coder **113**. In portion **(b)** of FIG. 3,  $T_w$  denotes the detection window width, which is the minimum unit of variation in the mark or space length in the write code sequence **126**. Portion **(c)** of FIG. 3 schematically illustrates marks and spaces to be actually recorded on the optical disk. The beam spot of the laser beam shifts from the left to the right in portion **(c)** of FIG. 3. The mark **301** is made so as to represent level "1" in the write code sequence **126**. The length of the mark **301** is proportional to that of the period that has level "1" in the write code sequence **126**. Portion **(d)** of FIG. 3 shows the count signal **205** according to the present invention, in which

the amount of time that has passed since the top of the mark **301** or space **302** is measured on a Tw basis. Portion **(e)** of FIG. 3 shows a mark length classification signal **307** in a conventional apparatus. In this conventional apparatus, the mark lengths are classified into odd-number-of-times longer ones and even-number-of-times longer ones. Portion **(g)** of FIG. 3 shows the mark length classification signal **204** of the present invention. In this preferred embodiment, the mark lengths are classified into the shortest code length of 2T, the second shortest code length of 3T, the third shortest code length of 4T, and the fourth shortest or less short code lengths, which are further classified into odd-number-of-times longer code lengths and even-number-of-times longer code lengths.

[0034]

Portions **(f)** and **(h)** of FIG. 3 show write waveforms for the conventional and inventive apparatuses, respectively, and are the counterparts of the write code sequence **126** shown in portion **(b)** of FIG. 3. These write waveforms **303** and **304** are generated by reference to the count signal **205** and write code sequence **126**. The conventional apparatus further refers to the mark length classification signal **307** in addition to those signals. On the other hand, the apparatus of the present invention refers to not only those signals but also the mark length classification signal **204** as well.

[0035]

In the apparatus of the present invention, the cooling time of the write pulse waveform **304** is never shorter than 1 Tw.

[0036]

Hereinafter, exemplary write waveforms **500** through **506** for the conventional apparatus will be described with reference to portions **(a)** through **(j)** of FIG. 5. The coder **113** is supposed to adopt a coding method in which every (1, 7) modulated code is always subjected to the NRZI modulation. For that reason, the mark and space lengths always fall within the range of 2 Tw through 8 Tw.

[0037]

FIG. 10 illustrates a configuration for the write processing system of the conventional apparatus.

[0038]

The mark length classifier **1001** shown in FIG. 10 divides the code length by the divisor of two (i.e., performs a remainder calculation). This mark length classifier classifies the marks and spaces of the write code sequence into ones of which the lengths are even numbers of times as long as the detection window width Tw and ones of which the lengths are odd numbers of times as long as the detection window width Tw.

[0039]

Portion **(b)** of FIG. 5 shows the count signal **1005** generated by the counter **1000**, which measures the length of time from a mark top position on a detection window width Tw

basis. The time at which the count signal goes zero corresponds to the top of a mark or space.

[0040]

Portion **(c)** of FIG. 5 shows a write pulse waveform while a mark with the 2 Tw length is being made. The mark making period **305** includes a pulse with a length of 1 Tw and a level Pw1. The non-mark-making period begins with a period with a length of 1 Tw and a level Pb and then maintains a level Pa until the next mark making period. Portion **(e)** of FIG. 5 shows a write pulse waveform while a mark with the 4 Tw length is being made. The mark making period **305** includes a pulse with the same length of 1 Tw and the same level Pw1 as the counterpart shown in portion **(c)** of FIG. 5, which is followed by a period with a length of 1 Tw and a level Pa and then a period with a length of 1 Tw and a level Pw3. After that, as shown in portions **(g)** and **(i)** of FIG. 5, in making a mark of which the length is an even number of times as long as the detection window width Tw, a period with a length of 1 Tw and a level Pa and another period with a length of 1 Tw and a level Pw3 are added per mark length of 2 Tw to the end of the mark making period. Portion **(d)** of FIG. 5 shows a write pulse waveform while a mark with the 3 Tw length is being made. The mark making period **305** includes a pulse with the same length of 1 Tw and the same level Pw1 as the counterpart shown in portion **(c)** of FIG. 5, which is followed by a period with a length of 1 Tw and a level Pw2. After that, as shown in

portions **(f)** and **(h)** of FIG. 5, in making a mark of which the length is an odd number of times as long as the detection window width Tw, a period with a length of 1 Tw and a level Pa and another period with a length of 1 Tw and a level Pw3 are added per mark length of 2 Tw to the end of the mark making period. The non-mark-making period begins with a period with a length of 1 Tw and a level Pb irrespective of the space length and then maintains the level Pa until the next mark making period. In the conventional write pulse waveform, the shortest cooling period in the mark making period **305** has a length of 1 Tw.

[0041]

FIG. 4 shows write pulse waveforms **400** through **407** according to the present invention. In this preferred embodiment, the coder **113** adopts a coding method in which the (1, 7) code modulation is followed by the NRZI modulation, and each and every mark or space length falls within the range of 2 Tw to 8 Tw. This coding method is also applicable to even a situation where a signal of 9 Tw, for example, is intentionally inserted as a sync signal. However, this does not amend the coding rule of the coder **113**. Rather, the present invention is applicable for use in the coder **113** that complies with any arbitrary coding rule (e.g., 8-16 modulation). The mark length classifier **201** shown in FIG. 2 classifies the code lengths of the marks to be made into the four groups of 2T, 3T, 4T and 5T or more. If the code length

**n** is 5T or more, the mark length classifier **201** divides (n-1) by the divisor of two (i.e., performs a remainder calculation). By using such a mark length classification signal, the marks and spaces of the write code sequence can be classified into ones that are even-number-of-times as long as the detection window width **Tw** and ones that are odd-number-of-times as long as the detection window width **Tw**. In this preferred embodiment, the divisor is supposed to be two for the sake of simplicity. However, this does not impose any limitation on how to classify the mark lengths. Thus, three or any other greater divisor may be used instead. Also, the mark length classifier **201** of this preferred embodiment operates so as to perform a remainder calculation. However, this never put any limitation on the structure or operation of the mark length classifier **201** but any other classification method may also be adopted.

[0042]

Portion **(b)** of FIG. 4 shows the count signal **205** generated by the counter **200**. The amount of time that has passed since the top of a mark is counted on a detection window width (**Tw**) basis. The time at which the count signal goes zero corresponds to the top of a mark or space.

[0043]

Portion **(c)** of FIG. 4 shows a write pulse waveform in making a mark with the 2 **Tw** length. In this case, the mark making period **305** consists of a single pulse with a length of

0.5 Tw to 1 Tw and a level Pw.

[0044]

Portion **(d)** of FIG. 4 shows a write pulse waveform in making a mark with the 3 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1 Tw to less than 2 Tw and a level Pw. It should be noted that in this case, the mark making period is supposed to be longer than that of the 2 Tw long one by at least 0.5 Tw.

[0045]

Portion **(e)** of FIG. 4 shows a write pulse waveform in making a mark with the 4 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1.5 Tw to less than 2.5 Tw and a level Pw. It should be noted that in this case, the mark making period is supposed to be longer than that of the 3 Tw long one by at least 0.5 Tw.

[0046]

Portion **(f)** of FIG. 4 shows a write pulse waveform in making a mark with the 5 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 TTW and a level Pw, which is followed by a period with a length of 1 Tw and a level Pe and then a period with a length of 1 Tw and a level Pw.

[0047]

After that, in making a mark that is an odd number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an

additional period with a length of 1 Tw and a level Pe and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portions **(h)** and **(j)** of FIG. 4.

[0048]

Portion **(g)** of FIG. 4 shows a write pulse waveform in making a mark with the 6 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 TTw and a level Pw, which is followed by a period with a length of 2 Tw and a level Pe and then a period with a length of 1 Tw and a level Pw.

[0049]

After that, in making a mark that is an even number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pe and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portion **(i)** of FIG. 4.

[0050]

In a non-mark-making period, the level of the signal waveform is maintained at Pe until the next mark making period irrespective of the space length. In this preferred embodiment, the shortest Pe level period (i.e., the shortest cooling period) during the mark making period **305** has a length of 1 Tw.

[0051]

As used herein, the "mark making period" refers to the interval between the leading edge of the first pulse and the trailing edge of the last pulse.

[0052]

Next, FIG. 6 shows write pulse waveforms 600 through 607 according to the present invention. In this preferred embodiment, the coder 113 also adopts the coding method in which the (1, 7) code modulation is followed by the NRZI modulation as in portions (a) through (j) of FIG. 4, and each and every mark or space length falls within the range of 2 Tw to 8 Tw. This coding method is also applicable to even a situation where a signal of 9 Tw, for example, is intentionally inserted as a sync signal. The mark length classifier 201 shown in FIG. 2 classifies the code lengths of the marks to be made into the four groups of 2T, 3T, 4T and 5T or more. If the code length  $n$  is 5T or more, the mark length classifier 201 divides  $(n-1)$  by the divisor of two (i.e., performs a remainder calculation). By using such a mark length classification signal, the marks and spaces of the write code sequence can be classified into ones that are even-number-of-times as long as the detection window width **Tw** and ones that are odd-number-of-times as long as the detection window width **Tw**. In this preferred embodiment, the divisor is supposed to be two for the sake of simplicity. However, this does not impose any limitation on how to classify the mark

lengths. Thus, three or any other greater divisor may be used instead. Also, the mark length classifier **201** of this preferred embodiment operates so as to perform a remainder calculation. However, this never put any limitation on the structure or operation of the mark length classifier **201** but any other classification method may also be adopted.

[0053]

Portion **(b)** of FIG. 6 shows the count signal **205** generated by the counter **200**. The amount of time that has passed since the top of a mark is counted on a detection window width ( $T_w$ ) basis. The time at which the count signal goes zero corresponds to the top of a mark or space.

[0054]

Portion **(c)** of FIG. 6 shows a write pulse waveform in making a mark with the 2  $T_w$  length. In this case, the mark making period **305** consists of a single pulse with a length of 0.5  $T_w$  to 1  $T_w$  and a level  $P_w$ .

[0055]

Portion **(d)** of FIG. 6 shows a write pulse waveform in making a mark with the 3  $T_w$  length. In this case, the mark making period **305** consists of a single pulse with a length of 1  $T_w$  to less than 2  $T_w$  and a level  $P_w$ . It should be noted that in this case, the mark making period is supposed to be longer than that of the 2  $T_w$  long one by at least 0.5  $T_w$ .

[0056]

Portion **(e)** of FIG. 6 shows a write pulse waveform in

making a mark with the 4 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1.5 Tw to less than 2.5 Tw and a level  $P_w$ . It should be noted that in this case, the mark making period is supposed to be longer than that of the 3 Tw long one by at least 0.5 Tw.

[0057]

Portion **(f)** of FIG. 6 shows a write pulse waveform in making a mark with the 5 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 TTw and a level  $P_w$ , which is followed by a period with a length of 1 Tw and a level  $P_b$  and then a period with a length of 1 Tw and a level  $P_w$ .

[0058]

After that, in making a mark that is an odd number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level  $P_b$  and another additional period with a length of 1 Tw and a level  $P_w$  per mark length of 2 Tw in the middle of the mark making period as shown in portions **(h)** and **(j)** of FIG. 6.

[0059]

Portion **(g)** of FIG. 6 shows a write pulse waveform in making a mark with the 6 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level  $P_w$ , which is followed by a period with a length of 2 Tw and a level  $P_b$  and then a period with a length of 1 Tw and a

level Pw.

[0060]

After that, in making a mark that is an even number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pb and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portion (i) of FIG. 6.

[0061]

In a non-mark-making period, the level of the signal waveform is maintained at Pe until the next mark making period irrespective of the space length. In this preferred embodiment, the shortest Pb level period (i.e., the shortest cooling period) during the mark making period 305 has a length of 1 Tw.

[0062]

As used herein, the "mark making period" refers to the interval between the leading edge of the first pulse and the trailing edge of the last pulse.

[0063]

Next, FIG. 7 shows write pulse waveforms 700 through 707 according to the present invention. In this preferred embodiment, the coder 113 also adopts the coding method in which the (1, 7) code modulation is followed by the NRZI modulation as in portions (a) through (j) of FIG. 4, and each

and every mark or space length falls within the range of 2 Tw to 8 Tw. This coding method is also applicable to even a situation where a signal of 9 Tw, for example, is intentionally inserted as a sync signal. The mark length classifier **201** shown in FIG. 2 classifies the code lengths of the marks to be made into the four groups of 2T, 3T, 4T and 5T or more. If the code length **n** is 5T or more, the mark length classifier **201** divides  $(n-1)$  by the divisor of two (i.e., performs a remainder calculation). By using such a mark length classification signal, the marks and spaces of the write code sequence can be classified into ones that are even-number-of-times as long as the detection window width **Tw** and ones that are odd-number-of-times as long as the detection window width **Tw**. In this preferred embodiment, the divisor is supposed to be two for the sake of simplicity. However, this does not impose any limitation on how to classify the mark lengths. Thus, three or any other greater divisor may be used instead. Also, the mark length classifier **201** of this preferred embodiment operates so as to perform a remainder calculation. However, this never put any limitation on the structure or operation of the mark length classifier **201** but any other classification method may also be adopted.

[0064]

Portion **(b)** of FIG. 7 shows the count signal **205** generated by the counter **200**. The amount of time that has passed since the top of a mark is counted on a detection

window width (Tw) basis. The time at which the count signal goes zero corresponds to the top of a mark or space.

[0065]

Portion **(c)** of FIG. 7 shows a write pulse waveform in making a mark with the 2 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 0.5 Tw to 1 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw to 1.5 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0066]

Portion **(d)** of FIG. 7 shows a write pulse waveform in making a mark with the 3 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1 Tw to less than 2 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period. It should be noted that in this case, the mark making period is supposed to be longer than that of the 2 Tw long one by at least 0.5 Tw.

[0067]

Portion **(e)** of FIG. 7 shows a write pulse waveform in making a mark with the 4 Tw length. In this case, the mark making period **305** consists of a single pulse with a length of 1.5 Tw to less than 2.5 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a

level  $P_c$  and then the  $P_e$  level is maintained until the next mark making period. It should be noted that in this case, the mark making period is supposed to be longer than that of the 3 Tw long one by at least 0.5 Tw.

[0068]

Portion **(f)** of FIG. 7 shows a write pulse waveform in making a mark with the 5 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 Tw and a level  $P_w$ , which is followed by a period with a length of 1 Tw and a level  $P_b$  and then a period with a length of 1 Tw and a level  $P_w$ . The non-mark-making period begins with a period with a length of 1 Tw and a level  $P_c$  and then the  $P_e$  level is maintained until the next mark making period.

[0069]

After that, in making a mark that is an odd number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level  $P_b$  and another additional period with a length of 1 Tw and a level  $P_w$  per mark length of 2 Tw in the middle of the mark making period as shown in portions **(h)** and **(j)** of FIG. 7. The non-mark-making period begins with a period with a length of 1 Tw and a level  $P_c$  and then the  $P_e$  level is maintained until the next mark making period.

[0070]

Portion **(g)** of FIG. 7 shows a write pulse waveform in

making a mark with the 6 Tw length. In this case, the mark making period **305** includes a pulse with a length of 1 TTw and a level Pw, which is followed by a period with a length of 2 Tw and a level Pb and then a period with a length of 1 Tw and a level Pw. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0071]

After that, in making a mark that is an even number of times as long as the detection window width Tw, the write pulse waveform during the mark making period includes an additional period with a length of 1 Tw and a level Pb and another additional period with a length of 1 Tw and a level Pw per mark length of 2 Tw in the middle of the mark making period as shown in portion **(i)** of FIG. 7. The non-mark-making period begins with a period with a length of 1 Tw and a level Pc and then the Pe level is maintained until the next mark making period.

[0072]

In this exemplary write pulse waveform, the shortest Pb level period (i.e., the shortest cooling period) during the mark making period **305** has a length of 1 Tw.

[0073]

Also, in this exemplary write pulse waveform, the Pc level lasts for at least 1 Tw during the non-mark making period.

[0074]

As used herein, the "mark making period" refers to the interval between the leading edge of the first pulse and the trailing edge of the last pulse.

[0075]

In this preferred embodiment, these levels  $P_c$  and  $P_b$  are supposed to be two different power levels. Alternatively, the levels  $P_c$  and  $P_b$  may be set equal to each other.

[0076]

Next, an example of adaptive mark compensation will be described with reference to the accompanying drawings. A high-density optical write operation sometimes causes write interference in which mark edges shift depending on the writing conditions. To prevent the write signal from being deteriorated by such interference, adaptive mark compensation may be carried out.

[0077]

The adaptive mark compensation means a compensation operation of changing the top incidence points or pulse widths of the laser beam according to the length of the given mark, i.e., whether the length of the mark is  $2T$  ( $2T_m$ ),  $3T$  ( $3T_m$ ),  $4T$  ( $4T_m$ ) or  $5T$  or more ( $\geq 5T_m$ ), as shown in FIG. 8.

[0078]

FIG. 8 shows exemplary adaptive mark compensation in a situation where the write power is represented by binary values.

[0079]

By shifting dTtop and Ttop with respect to the beginning of the mark and also shifting Tlp or dTlp with respect to the end of the recording mark according to the code length of the recording mark, among other parameters described above, the edge shifting at the beginning and end of the mark can be minimized and good signal quality is realized.

[0080]

FIG. 9 shows exemplary adaptive mark compensation in a situation where the write power is represented by four values.

[0081]

By shifting dTtop and Ttop with respect to the beginning of the mark and also shifting dTe with respect to the end of the recording mark according to the code length of the recording mark, among other parameters described above, the edge shifting at the beginning and end of the mark can be minimized and good signal quality is realized. Although the write power is supposed to be represented by four values in this example, the same mark compensation is equally applicable to even a situation where three values are used by setting Pb =Pc.

[0082]

The magnitude of shift that can be caused by the write compensation may be defined by a very small step (of Tw/16, for example) with respect to the reference clock signal using a delay line, for instance.

[0083]

[Effects of the Invention]

According to the present invention, an apparatus for writing information on a storage medium by applying energy to the storage medium and making marks that have a different physical property from the non-recorded portion thereof can make those marks quickly and accurately. As a result, the mark edge recording technique, which will effectively contribute to increasing the recording linear density, can be adopted as the method of recording. Consequently, the read/write operations can be done more quickly and with more reliability, and yet the sizes of the apparatus for writing information and the storage medium can be reduced as well. That is why the present invention is very cost-effective.

[Brief Description of the Drawings]

[FIG. 1]

Shows an overall configuration for an information recorder according to the present invention.

[FIG. 2]

Shows a configuration for the write processing system of the present invention.

[FIG. 3]

Shows how the write processing system works in the present invention and in the prior art.

[FIG. 4]

Shows an exemplary set of write pulse waveforms for a

write processing system according to the present invention.

[FIG. 5]

Shows write pulse waveforms for a conventional write processing system.

[FIG. 6]

Shows another exemplary set of write pulse waveforms for the write processing system of the present invention.

[FIG. 7]

Shows still another exemplary set of write pulse waveforms for the write processing system of the present invention.

[FIG. 8]

Shows how adaptive mark compensation can be done according to the present invention.

[FIG. 9]

Shows how adaptive mark compensation can be done according to the present invention.

[FIG. 10]

Shows a configuration for a conventional write processing system.

[Description of the Reference Numerals]

**110** laser

**111** laser driver

**112** write waveform generator

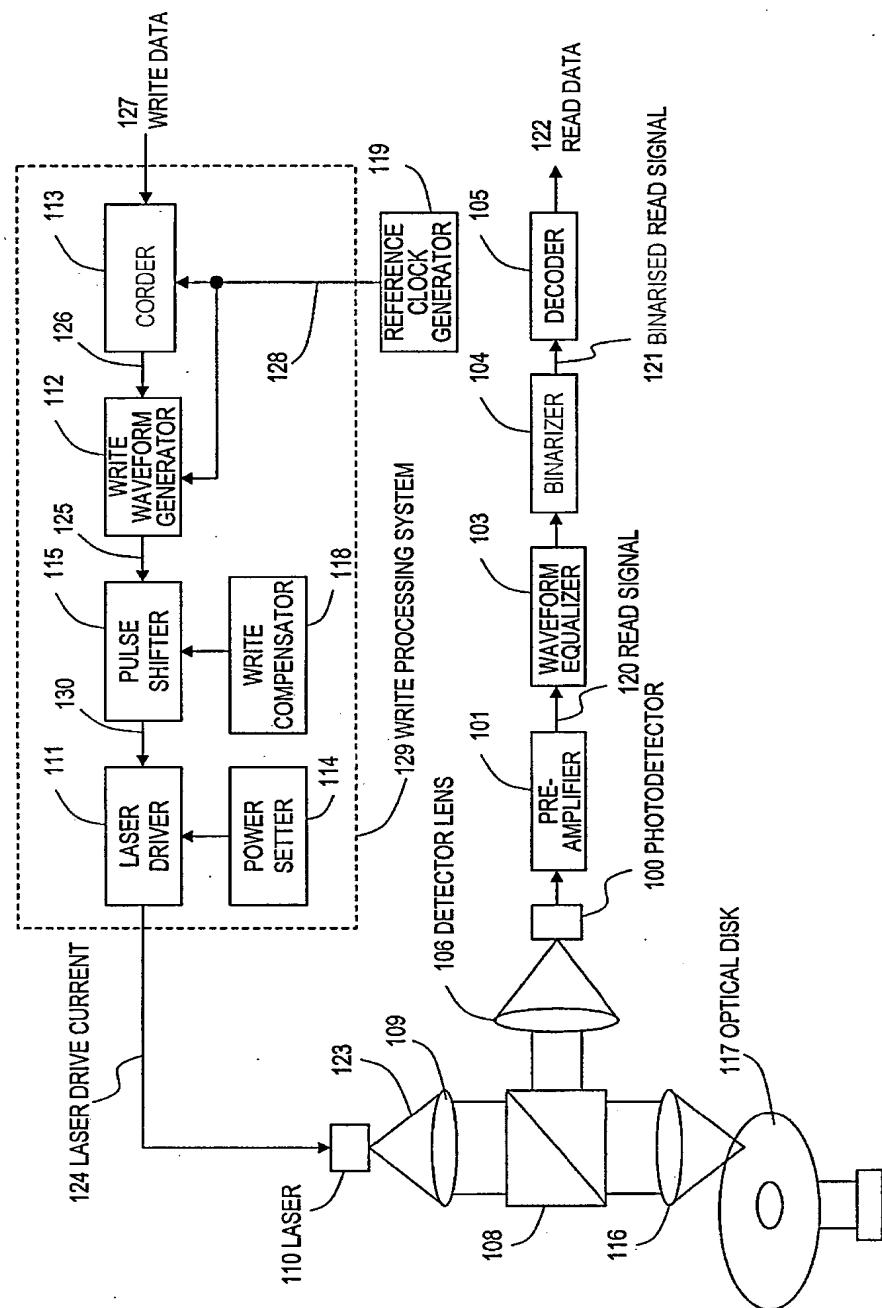
**113** coder

**117** optical disk

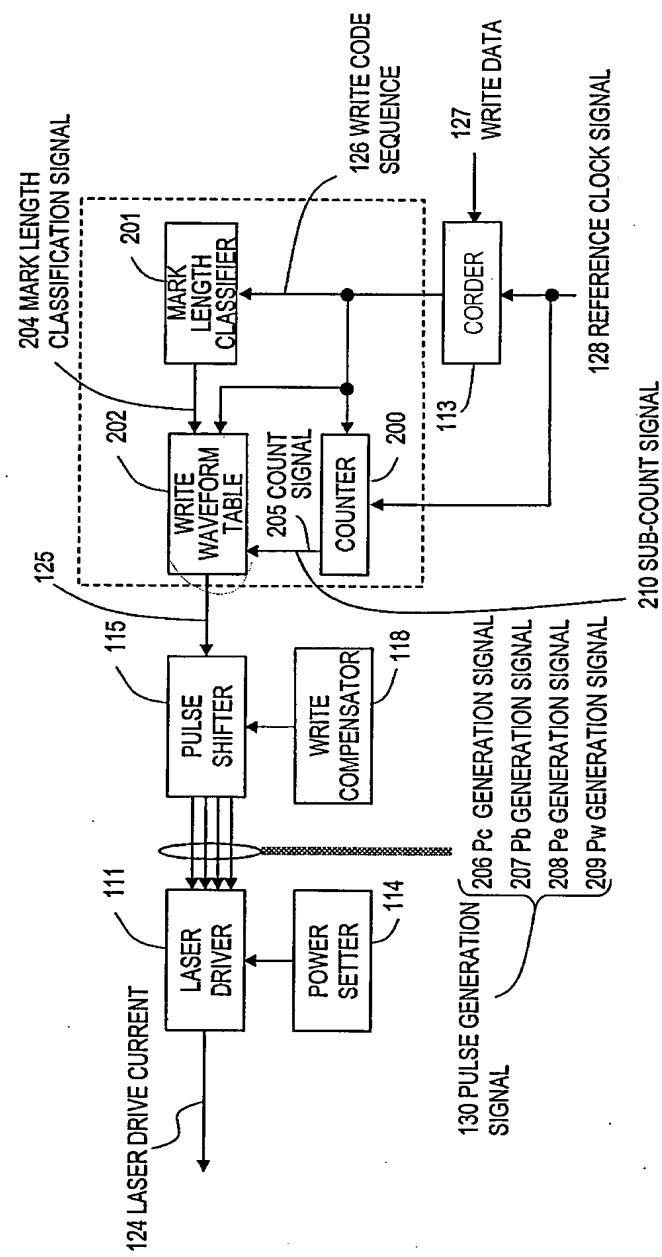
**119** reference clock generator  
**122** read data  
**126** write code sequence  
**127** write data  
**128** reference clock signal  
**129** write processing system  
**200** counter  
**201** mark length classifier  
**202** write waveform table  
**204** mark length classification signal  
**305** mark making period

[Name of Document] Drawings

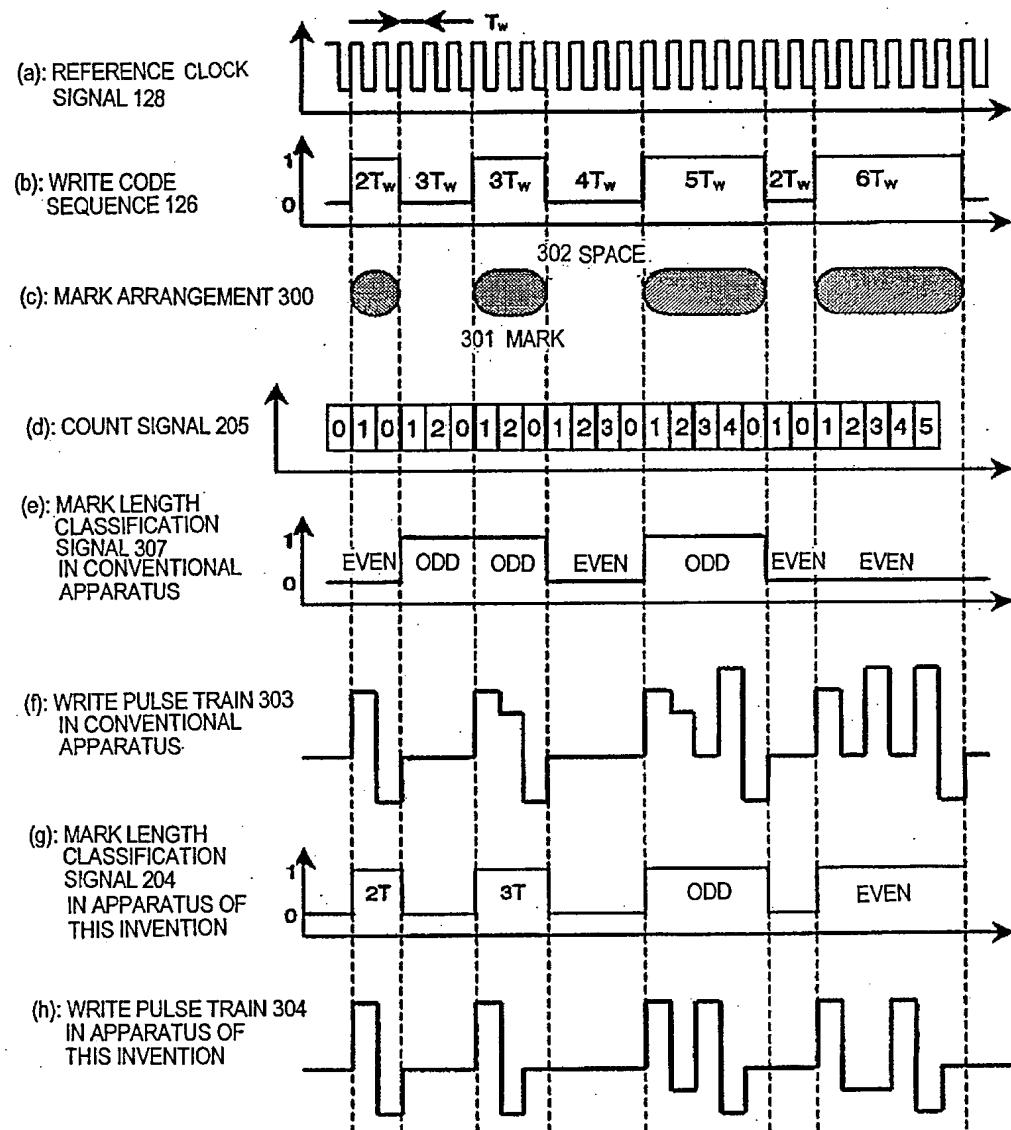
[Fig.1]



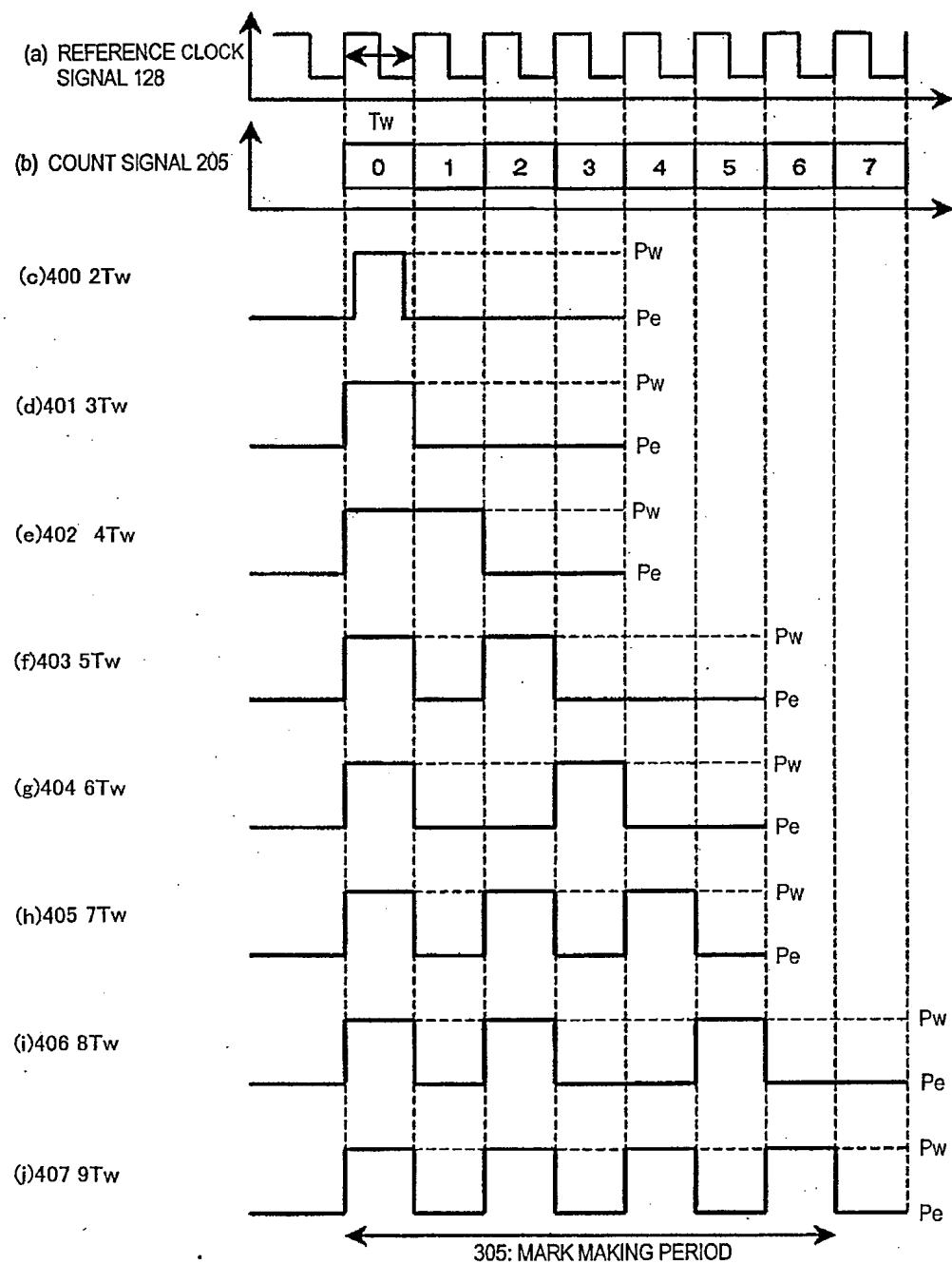
[Fig. 2]



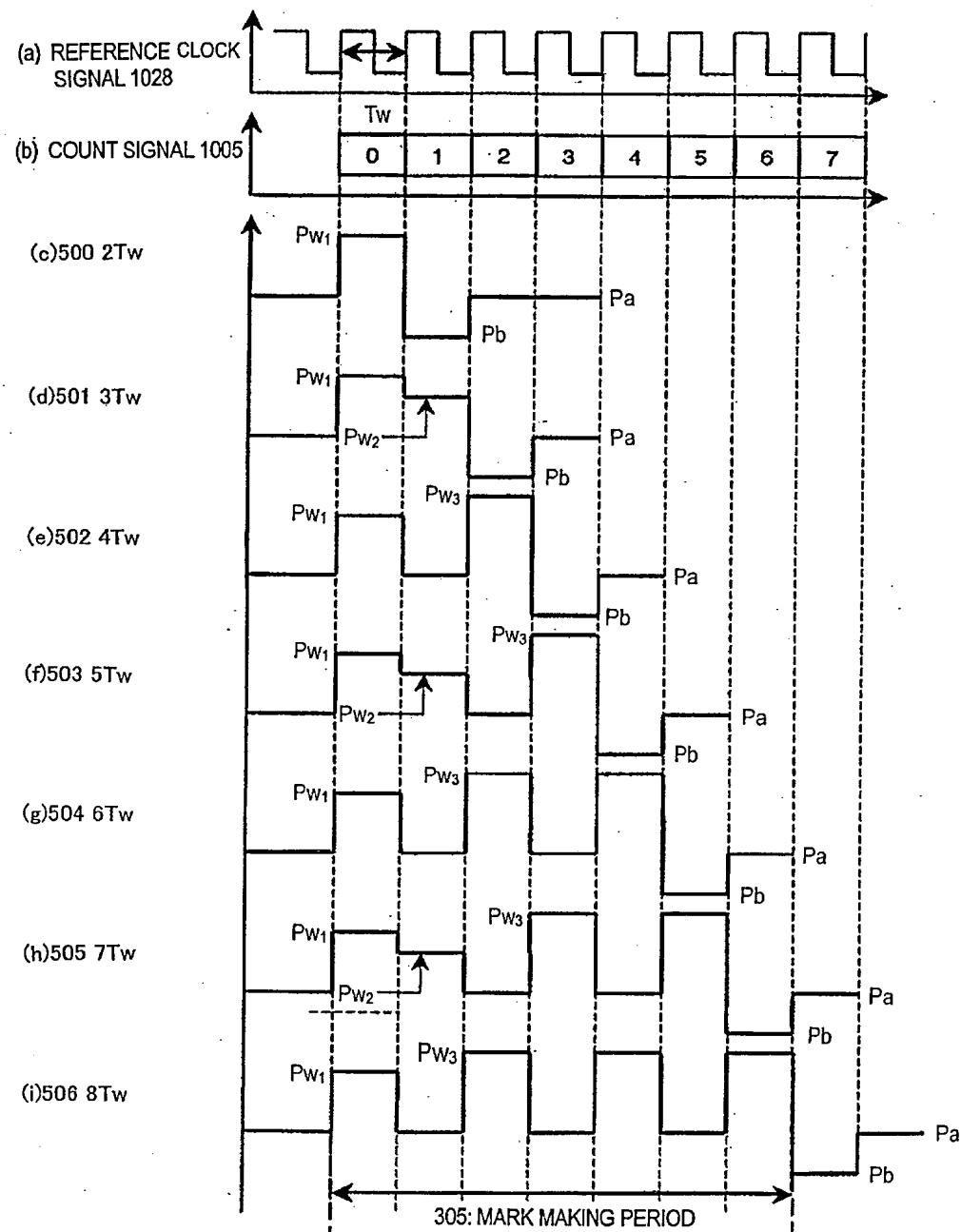
[Fig.3]



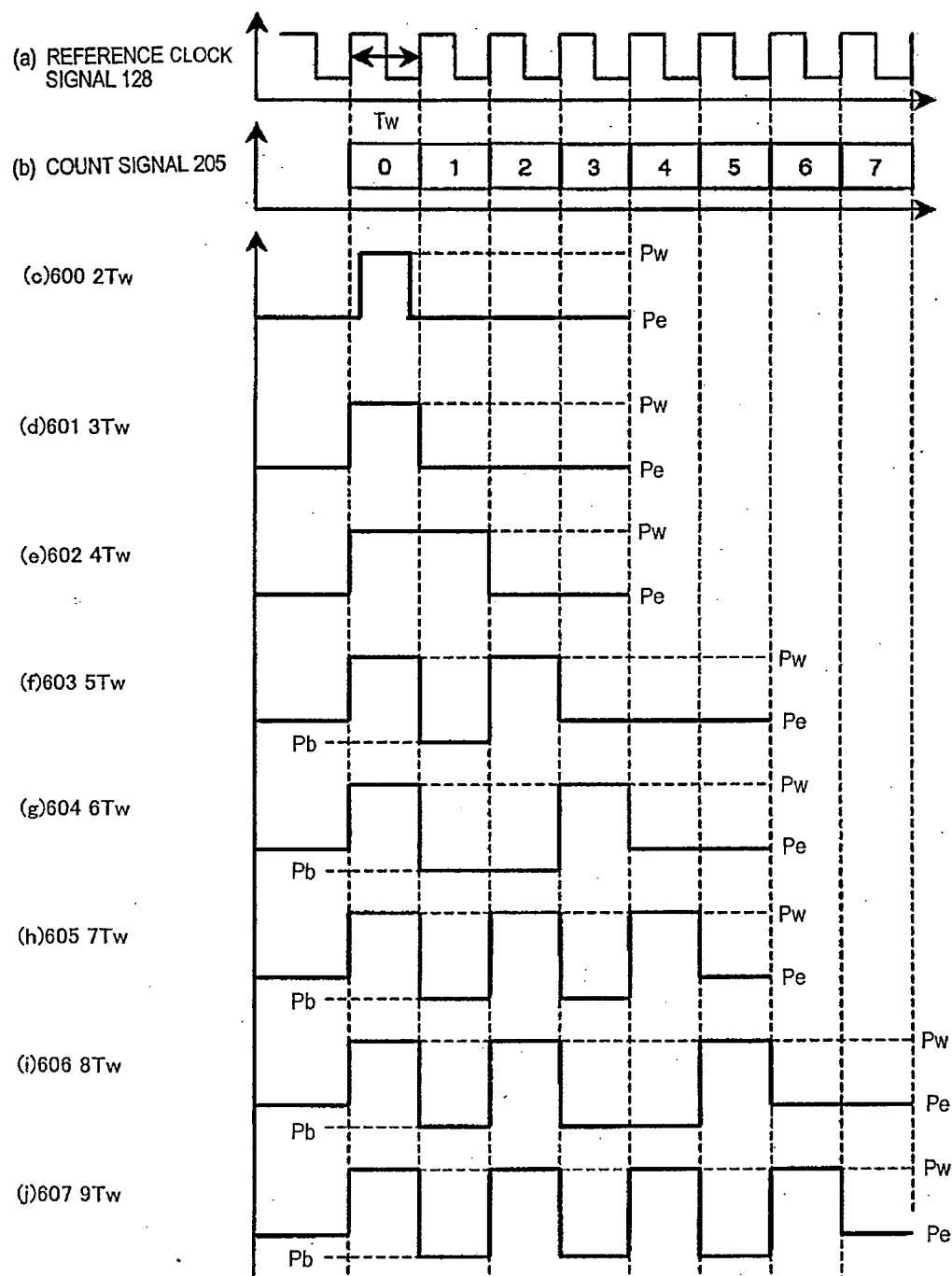
[Fig.4]



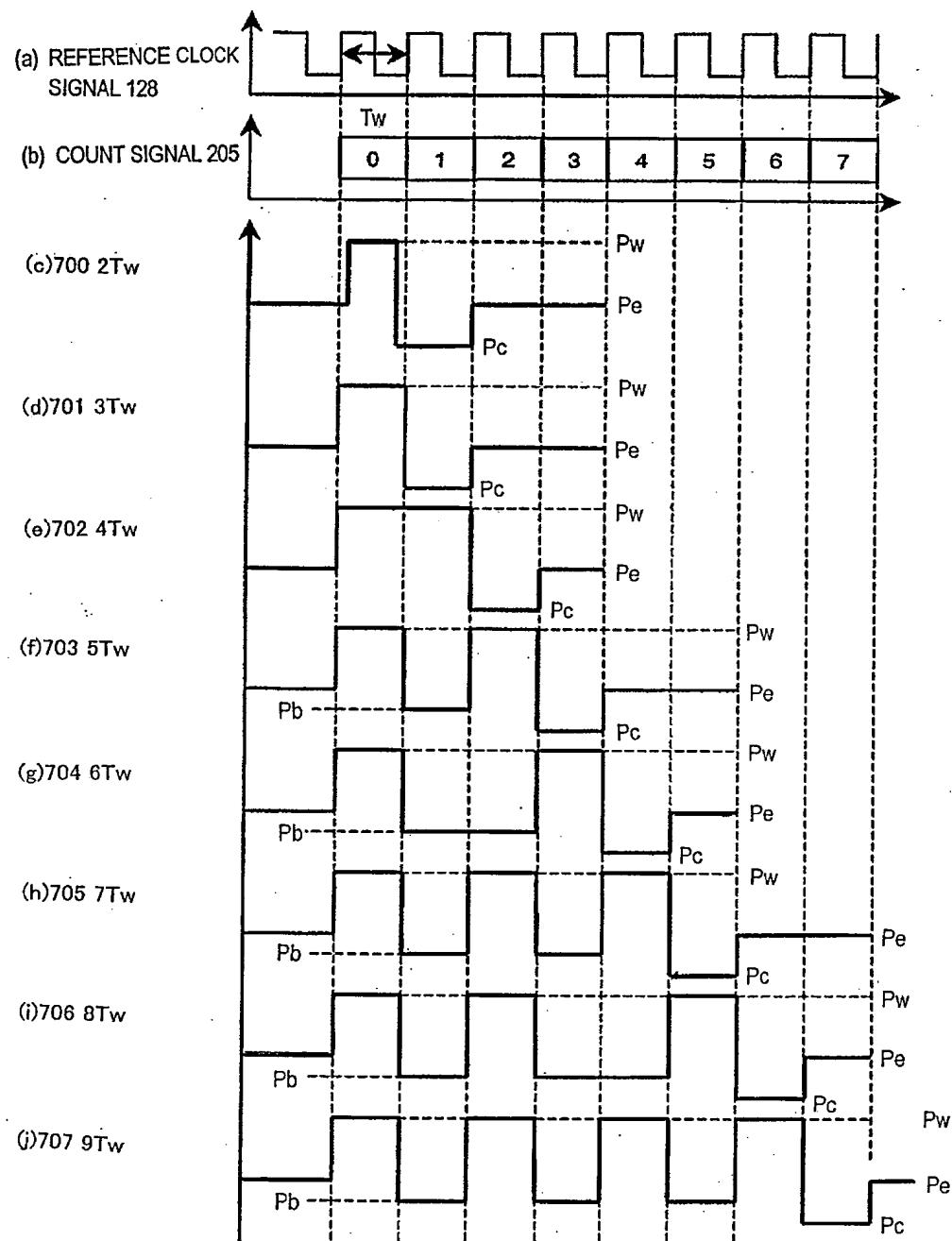
[Fig.5]



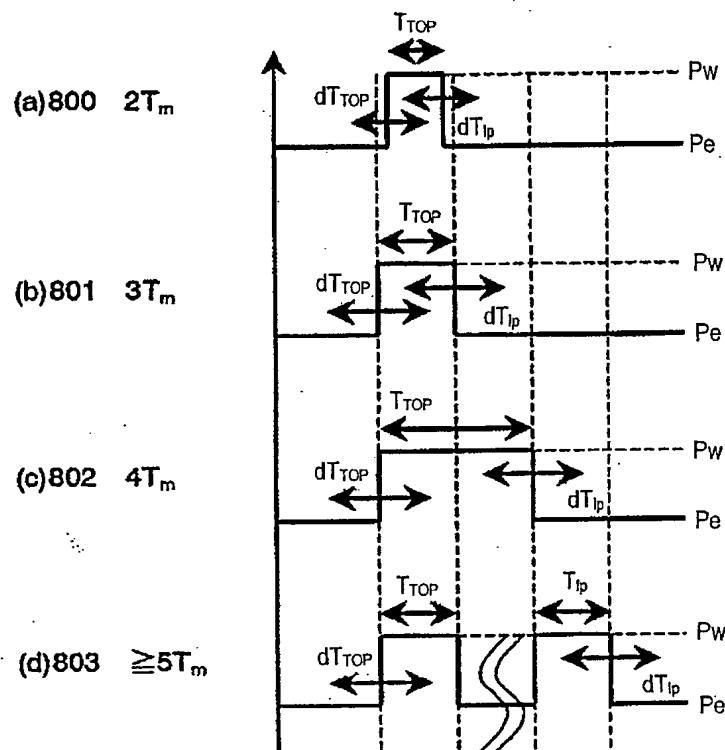
[Fig. 6]



[Fig. 7]



[Fig. 8]



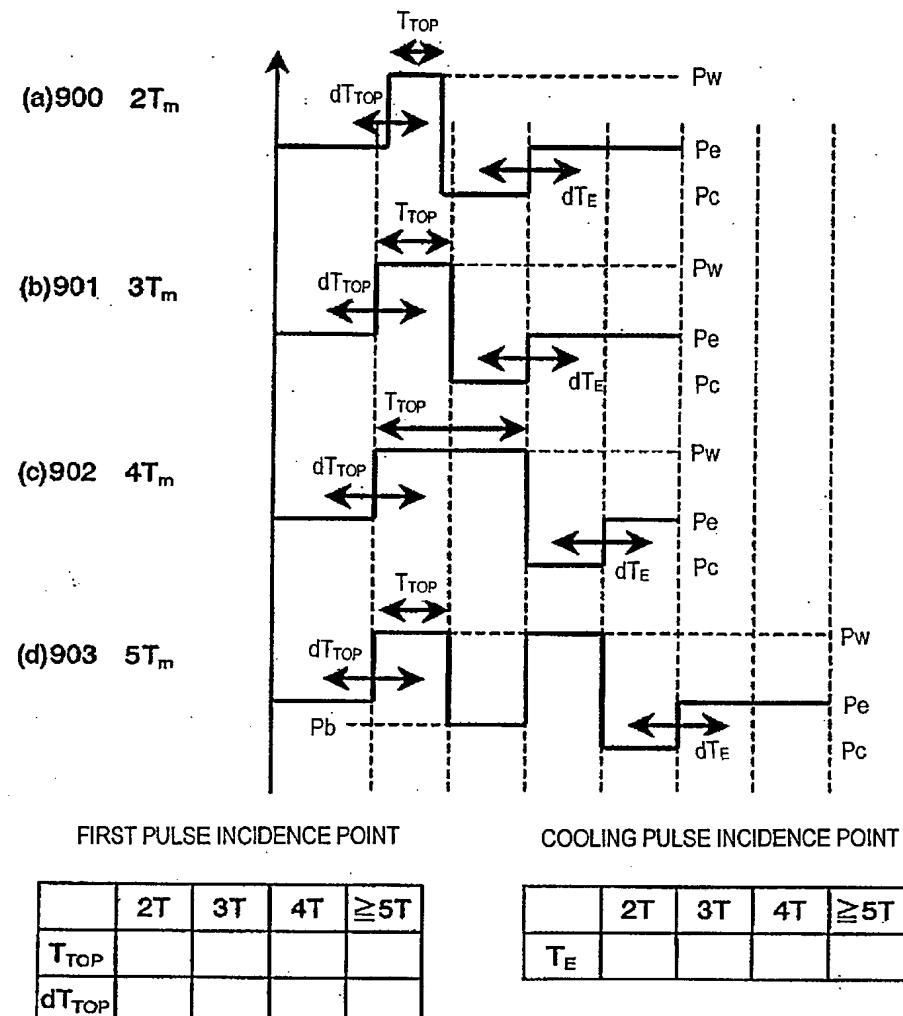
FIRST PULSE INCIDENCE POINT

	2T	3T	4T	$\geq 5T$
$T_{TOP}$				
$dT_{TOP}$				

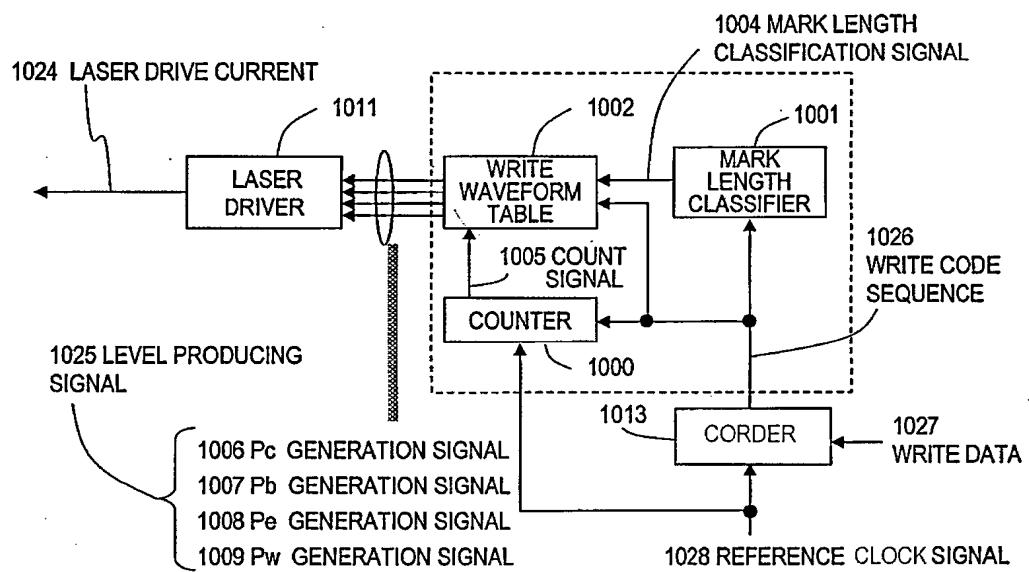
LAST PULSE INCIDENCE POINT

	2T	3T	4T	$\geq 5T$
$T_{Ip}$				
$dT_{Ip}$				

[Fig. 9]



[Fig.10]



[Name of the Document] ABSTRACT

[Abstract]

[Problem] To make a mark with high accuracy and at high speeds using an optical disk recorder/player for writing information on an optical disk medium by applying laser power to the medium and making a region with a different physical property from a non-recorded portion thereof.

[Means for Solving the Problem] To drive the laser more easily during writing and allow the optical disk medium an ample cooling time, means for driving energy generating means is provided to change the energies and number of pulses applied during a mark making period according to the mark length such that the interval between two arbitrary variation points of the energy applied per unit time while information is being written becomes equal to or greater than, or approximately a natural number of times as long as, the detection window width.

[Selected Figure] FIG. 1